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Determination of phytosociological characteristic, biodiversity conservation dynamics and biomass potentials in a Nigerian protected forest

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ABSTRACT: Tropical rainforest contributes immensely to the richness, diversity and productivity of ecosystem. This study aimed to determine the structure, biodiversity and carbon stocks of Okomu protected forest in Nigeria. Simple random technique was adopted in selection of 9 compartments and in each compartment 4 plots of size was selected with 36 plots of (25 m x 25 m x 36 plots), making a total of 2.25 ha selected from the entire forest. Shannon-Wiener diversity index, Shannon's equitability of species evenness, Margalef's index of species richness and volume equations were used to determine species diversity, evenness, richness and tree structure respectively. There were 790 individual trees, 351 stems ha^{-1} belonging to 67 tropical hardwood species, 86 genera and 31 families. About 24% of tree species in this protected forest were among tree species that needs urgent conservation measures. The total volume was estimated to be from 1970.40 to 9437.76 m^3 with an average of 4643.20 m^3 ha^{-1}, an indication of vertical and horizontal structure confirm the growing natural of this protected forest. Accumulation of total biomass was estimated to be from 1150.72 to 6795.20 kg ha^{-1} with an average of 2927.72 kg ha^{-1}. The carbon stock in this protected forest was estimated to be from 575.36 to 3397.60 kg ha^{-1} with an average of 1463.88 kg ha^{-1}. The forest serves as biodiversity hotspot due to high Shannon-Wiener index and evenness computed for the compartments. This serves as information for management of protected forests, with potentials for nature conservation and carbon sequestration.

KEY WORDS: Biodiversity, conservation, *Celtis zenkeri*, ecosystem services, *in-situ*, national park, protected forest.

INTRODUCTION

Global forests have the potential to generate ecosystem services in terms of biodiversity conservation, carbon sequestration, mitigation of climate change, habitats for animals, timber production and sustainability of human livelihood (Sandifer *et al.,* 2015; Stoklosa *et al.,* 2016; Agbelade and Onyekwelu, 2020). Forest contributes immensely in the regulation of local, global climate and reducing the adverse effects of climate change and global warming on the environment (Keenan, 2015; Steffen *et al.,* 2015). The global environmental changes occasioned by deforestation have affected directly and indirectly the ecology of tropical forests resources in delivering the services required. These benefits of vegetation cover include tangible and intangible benefits that protect the environment to deliver maximum potentials (Reid *et al*., 2005). Carbon sequestration, production of oxygen and Ozone layer protection are some of the services delivered by the forest (Adalarsan *et al.,* 2007; Alves *et al.,* 2010; Adekunle *et al.,* 2014; Agbelade and Adeagbo, 2020). Furthermore, forest vegetation covers protect Watersheds, conserve species diversity, and serve as habitat to wildlife, and thus contribute to a good quality environment. More than half of the world's species diversity can be found in the tropics according to a study by May and Stump (2000). The forest is regulators of the micro and macro environment of carbon stock and carbon sequestration (Kenzo *et al.,* 2009; Agbelade and Adeagbo, 2020). The estimation of carbon stock and carbon sequestration rate has gained importance since carbon stock was introduced as a commodity in the world market (Ekanayake *et al.,* 2012). Over 50% of global greenhouse gas emission potential can be mitigated through the forests, which accounts for 20% of carbon emissions (Ambagahaduwa *et al.,* 2009).

Nigeria protected forests are essentially reservoir of biodiversity, carbon sinks for mitigation of climate change and are important component of the forest for healthy ecosystem services provision (Adekunle *et al.,* 2013; Adekunle *et al.,* 2014; Agbelade and Onyekwelu, 2020). This is very important for the preservation of all living organisms, as they provide valuable services and functions to the micro environment. The improvement of micro and macro environments is possible due to the contribution of protected forests for healthy ecosystem functions. National parks, forest reserves, sacred groves, strict nature reserve, biosphere reserve and community-based forest heritages are some of the protected forests in Nigeria that are of importance to the environments. The methods of management of the protected forests are dependent on the policies of the Federal and State governments in Nigeria. Protected forests in Nigeria play vital role in biodiversity conservation, volume of biomass stored, and the amount of carbon sequestrate by plants. They are natural storehouses of biomass and carbon in regulating the atmosphere for healthy environment. The method adopted by the government to promote ecosystem sustainability; make the forest to play essential role in carbon sequestration and functions as climate change

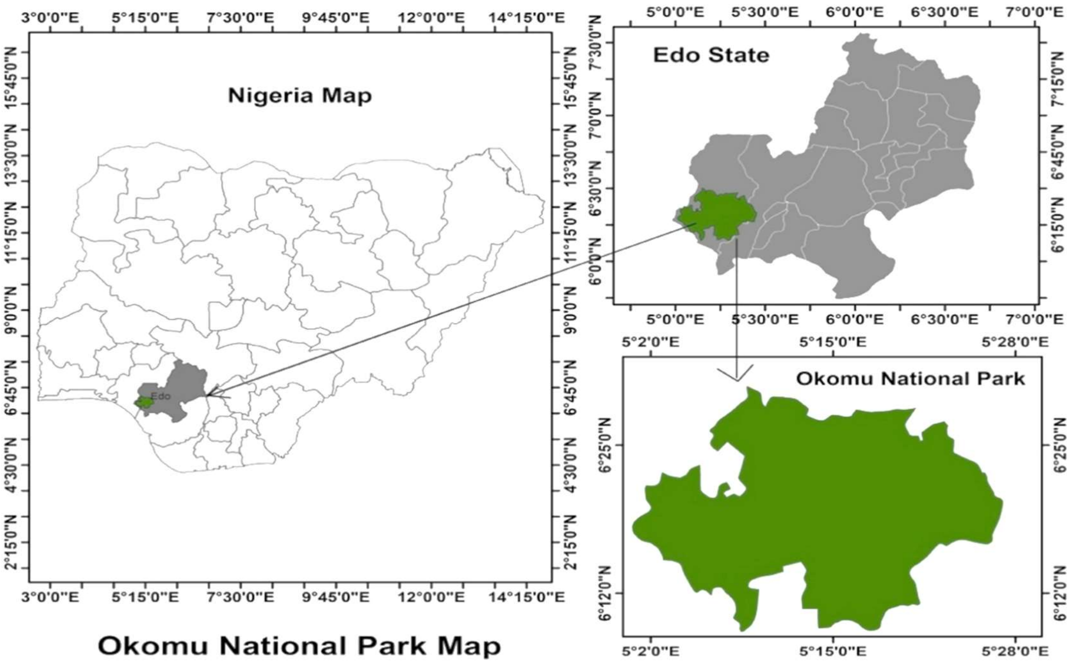

Fig. 1. Map of the study area (Okomu National Park)

regulator. Thus, increase in carbon sequestration can be achieved through conservation and effective management of forests.

Through the use of inventory tools, it is possible to access the level of forest development and growth. Density is an important factor in determining the level of carbon sequestration processes for different forests. The non-destructive method and biomass expansion factor equation were used for the study. There are different researches conducted on the composition of tree species in some forest reserves in the southwestern, Nigeria (Onyekwelu *et al.,* 2008; Adekunle *et al.,* 2013; Onyekwelu and Olusola, 2014; Agbelade and Ojo, 2020; Onyekwelu *et al.,* 2021). However, not all tropical rainforest land-use systems have been adequately investigated for can stock accumulation, one of which is Okomu protected forest. There are no known studies to provide information on structure, species diversity, biomass, and carbon stock as ecosystem services of Okomu protected forest.

This study was conducted to determine the phytosociological characteristic, biodiversity conservation dynamics and biomass potentials in a Nigerian protected forest. Therefore, this study addressed two major research objectives: 1. Assess the contribution of protected forest to tree species structure and biodiversity conservation status of the ecosystem. 2. Determine the volume of biomass and amount of carbon storage that can be sequestered from the atmosphere by the forest. These objectives were achieved through field inventory and on-the-spot tree diversity assessment on the Okomu protected forest.

MATERIALS AND METHODS

Study area

The research was conducted in Okomu protected forest, a forest block covering an area of 20,200 hectare in Edo State, about 60 km Northwest of Benin City, Nigeria (Figure 1). The park holds a small part of the forests that once covered the region and is the last habitat for many endangered species. The area is bounded by latitudes 6.08° and 6.30° N and longitudes 5.01° and 5.27° E. The forest is characterized by a relatively flat to very gently undulating plains that are formed on sedimentary rocks and littoral deposits (Ojanuga, 2006). The climate of the region is characterized by a double maximal year-round rainfall pattern with a mean annual rainfall of about 2200 mm which peaks between May and October and a mean monthly temperature of 27 °C. There are three layers of trees in the reserve, consisting of lower, middle and tall trees storeys. Some tree species in the area include *Celtis zenkeri, Triplochiton scleroxylon, Pycnanthus angolensis*, *Alstonia congoensis, Khaya ivorensis* (African mahogany) and *Lovoa trichilioides* (African walnut).

Method of data collection

Okomu forest reserve consist of 79 compartments, nine (9) compartments which represent 11.39% were randomly selected and four quadrat plots were mapped out from each compartment to give 36 plots in total for data collections. In each compartment, line transect of 1000 m long was laid and quadrat plots size of 25 m × 25 m (625 m^2) were laid on alternate direction at 250 m intervals. In all a total of 2.25 ha (25 m × 25 m × 36 plots) was sampled in the entire forest reserve. Measurement of the trees greater than or equal to 10 cm diameter at breast height (dbh) and diameter at the base (db), middle (dm) and top (dt) were measured using girth diameter tape and Spiegel relaskop respectively.

Data analysis for species diversity

Species Relative Density (RD) used to determine species relative distribution was computed using:

$$RD = \frac{n_i}{N} \times 100 \quad (1)$$

Where: RD (%) = species relative density; n_i = number of individuals of species i; N = total number of all individual trees of all species in the sampled quadrats of the forest.

Species Relative Dominance (RD_0) was estimated using:

$$RD_0 = \left(\frac{\sum Ba_i \times 100}{\sum Ba_n}\right) \quad (2)$$

Where: Ba_i = basal area of all trees belonging to a particular species *i*; Ba_n = basal area of all individual tree.

Importance Value Index (IVI) of each species was computed with the relationship:

$$IVI = \left(\frac{RD + RD_0}{2}\right) \quad (3)$$

Species diversity index (H') was computed using the Shannon-Wiener diversity index below:

$$H' = -\sum_{i=1}^{s} Pi \; In(Pi) \quad (4)$$

Where: H' = Shannon-Wiener diversity index; S = total number of species in the forest reserve; p_i = proportion of S made up of the ith species; ln = natural logarithm.

Simpson Concentration index

$$D = \Sigma\left(\frac{n_i}{N_i}\right)^2 = D = \frac{1}{\sum_{i=1}^{s} P_i^2} \quad (5)$$

In the Simpson index, p is the proportion (n_i/N_i) of individuals of one particular species found (n_i) divided by the total number of individuals found (N_i), Σ is still the sum of the calculations, and (S) is the number of species.

Shannon's maximum diversity index was calculated using:

$$H_{Max} = Ln\ (S) \quad (6)$$

Where: H_{max} = Shannon's maximum diversity index; S= total number of species in the sampled quadrats of the forest.

Species evenness in each plot was determined using Shannon's equitability (E_H), which was obtained using:

$$E_H = \frac{H'}{H_{Max}} = \frac{\sum_{i=1}^{s} P_i Ln\ P_i}{Ln\ (S)} \quad (7)$$

Forest structure

The following computations were computed for forest structure analyses. The basal area of each tree in the forest reserve was calculated using

$$BA = \frac{\pi D^2}{4} \quad (8)$$

Where: BA = Basal area (m^2), D = Diameter at breast height (cm) and π = pie (3.142). The total basal area for the plot was obtained by adding all trees basal area in the sampled quadrats of the forest.

Volume of individual trees were estimated using

$$V = \pi h \frac{D_b^2 + 4(D_m^2) + D_i^2}{24} \quad (9)$$

Where: V = Tree volume (m^3), π = 3.142, h = tree height (m) measurement, D_b, D_m and D_t = tree cross-sectional area at the base, at the middle and top of merchantable height respectively. The total volume for the forest reserve was obtained by adding all individual trees volume computed.

Biomass and carbon stock

In determining the total carbon (TC) stocks, estimation of AGB and BGB were computed. Biomass expansion factor (BEF) of 1.74 was used to estimate tree above ground biomass for tropical rainforest (Brown and Lugo, 1992), multiple by volume overbark (m^3 ha^{-1}) and wood density (kg).

$$Above-Ground\ Biomass\ (AGB) = BEF \times VOB \times WD \quad (10)$$

Where, BEF = Biomass expansion factor; VOB = Volume over bark (m^3); WD = Wood density (kg). Wood density for tree species was acquired from Global Wood Density Database (www.worldagroforestry.org). Arithmetic mean of (0.60 g cm^3) for a tropical African forest was used for species that were not found in the database following Chave *et al.,* (2005). The carbon stock of the protected forests was determined by a fraction of 50% of biomass.

$$AGC = AGB \times 0.5 \quad (11)$$

Thus, above ground carbon (AGC) was calculated as a conversion factor of 0.5 multiplied by AGB (Chave *et al.,* 2005).

$$BGB = AGB \times 0.2 \quad (12)$$

Where below ground biomass was computed as 20% of AGB following MacDicken (1997) and IPCC (2006), using a synthesis of global data and a conservative ratio shoot-to-root biomass of 5:1 (Meragiaw *et al.,* 2021).

$$TC = AGC + BGC \quad (13)$$

The estimation of carbon content in BGC is the same as that of AGC equation 12. Total carbon stock (TCS kg ha^{-1}) stock was calculated by summing up the carbon stock of AGC and BGC following Pearson *et al.,* (2007).

RESULTS

Phytosociological characteristics, diversity and biomass estimation

The floristic composition, vegetation structure and carbon stock of Okomu protected forest were analyzed in nine (9) compartments (Table 1). A total of 790 individual trees (351 ha^{-1}) stems, with 67 tree species and 31 families across all compartments in this forest site. The analyses of the phytosociological characteristics, diversity and biomass are summarized in Table 1. In all the compartments estimated, the family occurrence is from 11 to 20, with the highest number of family in compartments 44 and 62 (20 and 18) while individual trees is from 45 to 131 with compartments 36 and 53 (131 and 109) having the highest. The tree species richness, species evenness and Shannon-Wiener diversity is from16 to 35, 0.54 to 0.77 and 2.51 to 3.14 with highest tree species richness, species evenness and Shannon- Wiener

Table 1. Species structure, diversity, biomass and carbon stock estimation for the compartments

Compartments	No. of Family	No.Trees	No. of species	Volume (m^3)ha^{-1}	AGB (kg)ha^{-1}	BGB (kg)ha^{-1}	TCS (kg)ha^{-1}	H'	Hmax	E_H	SC
36	16	131	27	5610.24	2061.76	412.32	1237.12	2.63	4.88	0.54	0.10
43	11	68	22	4214.72	1450.72	290.08	870.4	2.79	4.22	0.66	0.08
44	20	103	25	2270.56	958.88	191.84	575.36	2.94	4.63	0.64	0.06
52	16	106	35	1970.4	1048.16	209.6	628.96	3.14	4.66	0.67	0.06
53	17	109	27	4136.8	1878.4	375.68	1127.04	2.60	4.69	0.55	0.13
54	15	45	21	3403.36	2451.2	490.24	1470.72	2.86	3.81	0.75	0.07
55	15	65	16	8446.24	5067.68	1013.6	3040.64	2.51	4.17	0.60	0.10
61	17	59	28	2298.72	1378.4	275.68	827.04	3.12	4.08	0.77	0.05
62	18	104	27	9437.76	5662.72	1132.48	3397.6	2.77	4.64	0.60	0.09
Total	145(31)	790	228(67)	41788.8	21957.92	4391.52	13174.88				0.74
Mean	16.11	87.78	25.33	4643.20	2439.77	487.95	1463.88	2.82	4.42	0.64	0.08
Standard Deviation	2.47	28.97	5.32	2707.24	1731.54	346.31	1038.91	0.22	0.36	0.08	0.03
Standard Error	0.76	8.9	1.61	848.63	545.96	108.59	326.53	0.07	0.11	0.03	0.01

Table 2. Compartments partitioning of the diameter distribution structure in the protected forest

Compartment	Dbh (cm)	BA/ha	Vol/ha	AGB/ha	BGB/ha	TCS/ha	IVI	H'	RD	RDo
	10 – 30	2.57	174.06	27.17	5.43	16.30	64.45	2.24	90.84	38.06
36	31 – 60	3.02	54.23	46.89	9.38	28.13	26.13	0.33	7.63	44.62
	>60	1.17	122.36	54.81	10.96	32.89	9.41	0.06	1.53	17.29
	10.0 - 30.0	1.70	13.15	9.71	1.94	5.83	18.84	0.95	27.94	9.73
43	31.0 - 60.0	4.00	91.21	36.12	7.22	21.67	30.57	1.07	38.24	22.90
	>60	11.78	159.07	44.84	8.97	26.91	50.61	0.77	33.82	67.40
	10.0 - 30.0	1.75	14.99	4.92	0.98	2.95	35.44	1.66	59.22	11.66
44	31.0 - 60.0	4.15	70.33	21.62	4.32	12.97	31.31	1.06	34.95	27.66
	>60	9.09	56.59	33.40	6.68	20.04	33.20	0.22	5.83	60.57
	10.0 - 30.0	3.57	37.98	20.62	4.12	12.37	54.13	2.34	76.42	31.84
52	31.0 - 60.0	3.66	43.85	17.93	3.59	10.76	26.23	0.64	19.81	32.65
	>60	3.96	41.31	26.97	5.39	16.18	19.56	0.15	3.77	35.35
	10.0 - 30.0	2.50	139.70	48.48	9.70	29.09	60.92	2.09	84.40	37.44
53	31.0 - 60.0	2.20	71.37	39.58	7.92	23.75	23.37	0.44	13.76	32.98
	>60	1.98	47.49	29.33	5.87	17.60	15.76	0.07	1.83	29.69
	10.0 - 30.0	1.94	155.82	135.99	27.20	81.59	70.36	2.50	84.44	56.27
54	31.0 - 60.0	1.52	56.90	17.22	3.44	10.33	29.86	0.35	15.56	44.16
	>60									
	10.0 - 30.0	1.01	309.82	137.60	27.52	82.56	15.36	0.85	26.15	4.56
55	31.0 - 60.0	3.54	492.95	94.78	18.96	56.87	33.36	1.12	50.77	15.95
	>60	17.63	1597.67	541.49	108.30	324.90	51.31	0.54	23.08	79.54
	10.0 - 30.0	2.33	13.67	10.43	2.09	6.26	43.54	2.04	64.41	22.66
61	31.0 - 60.0	4.07	71.11	45.79	9.16	27.48	33.34	0.78	27.12	39.56
	>60	3.89	58.89	29.93	5.99	17.96	23.17	0.30	8.47	37.87
	10.0 - 30.0	2.37	52.05	32.16	6.43	19.30	19.68	1.20	31.73	7.63
62	31.0 - 60.0	2.57	103.08	69.47	13.89	41.68	9.43	0.35	10.58	8.28
	>60	26.12	7103.31	1258.32	251.66	754.99	70.86	1.22	57.69	84.04

diversity are in compartments 52 and 61 (35 and 28); species evenness in compartments 61 and 54 (0.77 and 0.75) and Shannon-Wiener diversity are in compartments 52 and 61 (3.14 and 3.12). Simpson concentration index is from 0.05 to 0.13 with the highest in compartments 53 and 36 (0.10 and 0.13) (Table 1). Table 1 shows the volume yield, biomass pools, and carbon stock in different compartments in the natural forest of Okomu. The total volume was estimated to be from 1970.40 to 9437.76 m3 with an average of 4643.20 m^3 ha^{-1}. Accumulation of total biomass was estimated to be from 1150.72 to 6795.20 kg ha^{-1} with an average of 2927.72 kg ha^{-1}. The carbon stock in this protected forest was estimated to be from 575.36 to 3397.60 kg ha^{-1} with an average of 1463.88 kg ha^{-1} (Table 1). Among the established compartments, compartment 62 had the largest value of volume, biomass and carbon stock with 9437.76 m^3, 6795.20 and 3397.60 kg ha^{-1} (Table 1).

Compartments Partitioning of the Diameter distribution structure in the forest reserve

The pattern of volume, biomass, carbon stock and species diversity partitioning to tree dbh classes was not uniform among the compartments (Table 2). The pattern of biomass and carbon partitioning to tree dbh classes was not uniform among the compartments in this protected forest (Table 2). In this forest, compartments 62 and 55 have the majority of the volume, biomass and carbon stock were held by large diameter trees (dbh over 60 cm) while at compartments 53 and 54 smallest diameter trees

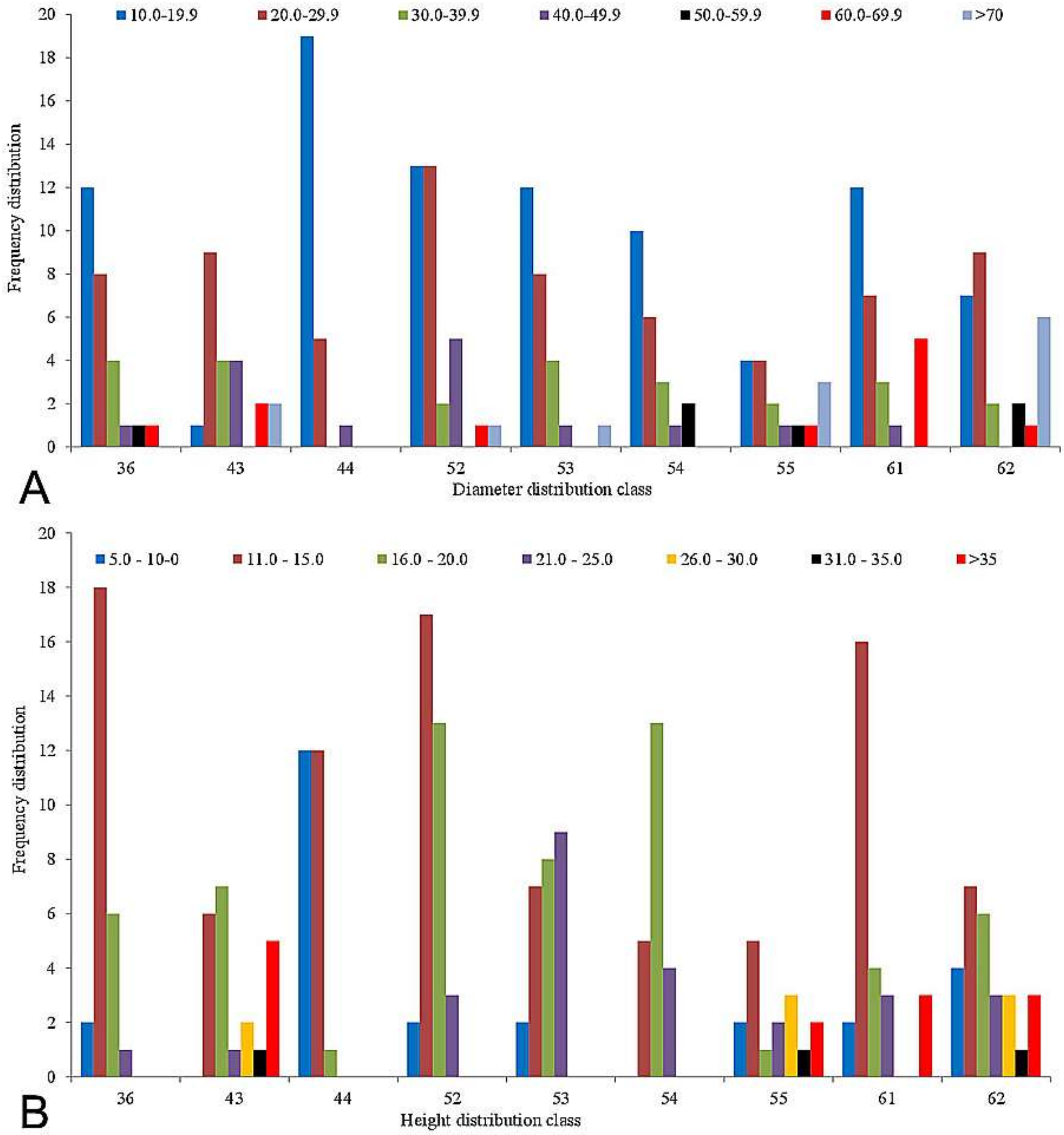

Fig. 2. Diameter and height distribution structure. **A**. Diameter distributions and **B**. Height distributions.

(dbh 10 – 30 cm) were responsible for highest volume, biomass and carbon stock. Different scenario played out in compartment 36 and 44 as the highest value was recorded for volume alone for (dbh, 0 – 30 cm) and (30 – 60 cm) while biomass and carbon stock values were recorded in the large diameter trees (dbh over 60 cm) (Table 2).

Diameter and height distribution structure

The diameter distribution of trees in each compartment followed inverted J distribution pattern (Figure 2). Between 45.5% and 96.0% of the trees across the nine (9) compartments fell within the low diameter range (dbh range: 10 – 30 cm), this determines the growing nature and regeneration potentials as healthy ecosystem of the forest. Large diameter trees (60 cm and above) accounted for between 3.9% and 33.3% of all the trees within the compartments. Only very few trees across the compartments had dbh of over 70 cm (Figure 2A). The height distribution of trees across the compartments in this forest fell in 11.0 – 15.9 m followed by 16.0 – 20.9 m and 21.0 – 25.9 m have the highest numbers of trees species. The dominants number of trees in this protected forest for all the compartments were distributed in the height class between 11.0–20.9 m (Figure 2B).

Forest tree conservation status

Based on FORMECU and IUCN red list of threatened species classification in this forest was listed as data deficient, least concern, near threatened, vulnerable, and endangered (Tables 3). Seven (7) species were near threatened (NT), while eight (8) were vulnerable to extinction and one (1) was endangered in this forest.

Table 3. Biodiversity and tree species conservation status in the protected forest.

Species	Family	Individual trees	Conservation status (NT; LC; EN; VU)	Dbh (cm) mean	Dbh (cm) (max)	RD (%)	RDo (%)	IVI (%)
Albizia ferruginea (Guill. & Perr.) Benth.	Fabaceae	3	Near Threatened	27.92	31.45	0.38	1.03	0.71
Allanblackia floribunda Oliv.	Clusiaceae	14	Least Concern	16.60	19.38	1.77	0.37	1.07
Alstonia boonei De Wild.	Apocynaceae	6	Least Concern	43.14	48.10	0.76	2.47	1.61
Alstonia congensis Engl.	Apocynaceae	11	Least Concern	11.20	17.40	1.39	0.17	0.78
Amphimas pterocarpoides Harms	Fabaceae	4	Least Concern	10.20	12.30	0.51	0.14	0.32
Anonidium mannii (Oliv.) Engl. & Diels	Annonaceae	24	Least Concern	15.71	17.20	3.04	0.33	1.68
Anthonata macrophylla P.Beauv.	Caesalpiniaceae	3		13.23	16.33	0.38	0.23	0.31
Baphia nitida Lodd.	Fabaceae	38	Least Concern	12.78	13.85	4.81	0.22	2.51
Bridelia grandis Pierre ex Hutch	Euphorbiaceae	22	Least Concern	18.35	18.35	2.78	0.45	1.62
Buchholzia coriacea Engl.	Capparaceae	4		18.43	24.13	0.51	0.45	0.48
Canthium latifolia Benth.	Rubiaceae	3		13.37	22.07	0.38	0.24	0.31
Ceiba pentandra (L.) Gaertn.	Malvaceae	3	Least Concern	61.00	96.65	0.38	4.93	2.65
Celtis zenkeri Engl.	Ulmaceae	98	Least Concern	12.37	13.50	12.41	0.20	6.30
Chrysophyllum albidum G.Don	Sapotaceae	1	Near Threatened	11.20	13.50	0.13	0.17	0.15
Chrysopogon nigritanus (Benth.) Veldkamp	Poaceae	12	Least Concern	15.09	16.95	1.52	0.30	0.91
Cleistopholis patens (Benth.) Engl. & Diels	Annonaceae	11	Least Concern	11.53	17.90	1.39	0.18	0.78
Cola gigantea A. Chev.	Malvaceae	16	Least Concern	18.89	19.50	2.03	0.47	1.25
Cola millenii K. Schum.	Sterculiaceae	7		10.56	12.20	0.89	0.15	0.52
Cola smithii Schott & Endl.	Malvaceae	1		21.00	25.30	0.13	0.58	0.36
Combretodendron africana Welw. ex Benth & Hook.	Lecythidaceae	6		11.97	13.60	0.76	0.19	0.47
Combretodendron macrocarpum (P. Beauv) Keay	Lecythidaceae	10		14.61	18.92	1.27	0.28	0.77
Cordia aurantiaca Baker.	Boraginaceae	1	Least Concern	48.60	54.40	0.13	3.13	1.63
Daniella ogea Harms	Bignoniaceae	5		26.16	31.02	0.63	0.91	0.77
Diospyros conocarpa Gurke & K.Schum.	Ebeneceae	16		17.00	17.88	1.01	0.38	0.70
Diospyros crassiflora Hiern	Ebenaceae	8	Vulnerable	21.63	24.23	2.03	0.62	1.32
Diospyros mesipiliformis Hochst ex D.AC	Ebanaceae	14		10.71	17.78	0.51	0.15	0.33
Drypetes gossweileri S.Moore	Putranjivaceae	4		20.00	32.70	0.51	0.53	0.52
Enantia chlorantha Oliv.	Annonaceae	8		21.47	24.80	1.01	0.61	0.81
Entandrophragma angolense (Welw.) C.DC.	Meliaceae	37	Near Threatened	32.60	39.49	4.68	1.41	3.05
Entandrophragma cylindricum Harms	Meliaceae	4	Near Threatened	78.00	94.30	1.77	8.06	4.92
Ficus exasperata Vahl	Moraceae	32	Least Concern	21.25	23.50	0.25	0.60	0.43
Funtumia elastica (Preuss.) Stapf.	Apocynaceae	23		21.50	32.06	2.91	0.61	1.76
Garcinia kola Heckel	Clusiaceae	1	Vulnerable	32.60	40.50	0.13	1.41	0.77
Leplaea lindheimeri (Engelm. & A.Gray) W.L.Wagner & Hoch	Onagraceae	1		14.60	17.50	0.13	0.28	0.20
Leplaea cedrata (A. Chev.)	Meliaceae	4	Vulnerable	18.00	29.15	4.30	0.43	2.37
Leplaea thompsonii Sprague & Hutch	Meliaceae	3	Vulnerable	21.50	30.50	0.38	0.61	0.50
Irvingia gabonensis Baill.	Irvingiaceae	6	Near Threatened	19.47	27.95	0.76	0.50	0.63
Khaya ivorensis A. Chev.	Meliaceae	9	Vulnerable	15.00	17.30	1.14	0.30	0.72
Lophira alata Banks ex Gaertn.	Ochnaceae	3	Vulnerable	21.30	33.00	0.38	0.60	0.49
Lovoa trichilioides Harms	Meliaceae	8	Least Concern	10.00	17.95	1.01	0.13	0.57
Macaranga bacteri Muell Arg.	Euphorbiaceae	12		30.90	52.00	1.52	1.26	1.39
Monodora myristica (Gaertn.) Dunal	Annonaceae	12	Least Concern	19.65	54.80	1.52	0.51	1.02
Musanga cecropioides R.Br.& Tedlie	Urticaceae	4	Least Concern	22.50	40.00	0.51	0.67	0.59
Myrianthus arboreus P. Beauv.	Urticaceae	18	Least Concern	26.35	38.50	2.28	0.92	1.60
Nauclea diderrichii (De wild) Merr.	Rubiaceae	9	Near Threatened	100.40	119.95	1.14	13.35	7.25
Okoubaka aubrevillei Pellgr. & Norman	Santalaceae	1	Endangered	23.30	28.80	0.13	0.72	0.42
Pausinystalia johimbe (K.Schum.) Pierre	Rubiaceae	1		12.70	13.80	0.13	0.21	0.17
Pentaclethra macrophllya Benth.	Fabaceae	10		18.95	21.93	1.27	0.48	0.87
Piptadeniastrum africana (Hook.f.) Brenan	Fabaceae	6		27.00	40.00	0.76	0.97	0.86
Porterandia cladantha K. Schum	Rubiaceae	4		24.30	37.63	0.51	0.78	0.64
Psydrax species Gaertn.	Rubiaceae	2		12.15	24.00	0.25	0.20	0.22
Pycnanthus angolensis (Welw.) Warb.	Myristicaceae	8	Least Concern	14.30	17.55	1.01	0.27	0.64
Rinorea dentata (P.Beauv.) Kuntze.	Violaceae	15		13.33	22.90	1.90	0.24	1.07
Spondias mombin Linn.	Anacardiaceae	13	Least Concern	28.70	34.60	1.65	1.09	1.37
Spathodea campanulata P.Beauv	Bignoniaceae	7	Least Concern	64.80	98.65	0.13	5.56	2.84
Staudtia stipitata Warb	Myristicaceae	7		20.00	25.35	0.89	0.53	0.71
Sterculia oblonga Mast.	Malvaceae	8	Vulnerable	37.40	41.60	9.11	1.85	5.48
Sterculia rhinopetala K. Schum.	Malvaceae	26	Least Concern	77.03	92.50	3.29	7.86	5.57
Sterculia tragacantha Lindl.	Sterculiaceae	68	Least Concern	16.60	19.00	0.51	0.37	0.44
Strombosia pustulata Oliv.	Olacaceae	5	Near Threatened	79.45	89.90	1.39	8.36	4.88
Terminalia ivorensis A. Chev.	Combretaceae	3	Vulnerable	24.95	46.90	0.38	0.82	0.60
Terminalia superba Engl. & Diels	Combretaceae	15		29.95	33.75	1.90	1.19	1.54
Tetrapleura tetraptera (Schum & Thonn)Taub	Fabaceae	8	Least Concern	21.00	25.05	1.01	4.93	2.97
Trichilia monadelpha (Thonn.) JJ De Wilde	Meliaceae	11	Least Concern	10.60	29.80	1.39	0.15	0.77
Triplochiton scleroxylon K.Schum	Malvaceae	6	Least Concern	46.05	49.30	0.76	2.81	1.78
Voacanga africana Stapf	Apocynaceae	8		29.45	36.90	1.01	8.36	4.69
Zanthoxylum zanthoxyloides (Lam.) Zepernich & Timter	Rutaceae	19	Least Concern	24.95	46.90	2.41	0.82	1.61

There were 16 different tree species in this protected forest with different conservation status, *Okoubaka aubrevillei* was listed as endangered, *Strombosia pustulata, Nauclea diderrichii, Irvingia gabonensis, Entandrophragma cylindricum, Entandrophragma angolense, Chrysophyllum albidum* and *Albizia ferruginea*which was near threatened, *Diospyros crassiflora, Garcinia kola, Leplaea cedrata*, *Leplaea thompsonii, Khaya ivorensis, Lophira alata*, *Sterculia oblonga,* and *Terminalia ivorensis* are in vulnerable category (Table 3). Families with high numbers of different species are Ulmaceae, Sterculiaceae, Fabaceae, Meliaceae, and Moraceae (Table 3). Thirty-One families were enumerated in this forest site, with Meliaceae, Rubiaceae, Malvaceae, Fabaceae, Apocynaceae and Annonaceae having the highest families (Table 4). About 52% of the families were represented by one species, 26% by two species and 22% by more than two species in this protected forest (Tables 4). The trees with high mean diameter at breast height across the compartments is *Nauclea diderrichii* (100.40 cm), *Strombosia pustulata* (79.45 cm), *Entandrophragma cylindricum* (78.00 cm), *Sterculia rhinopetala* (77.03 cm), *Spathodea campanulata* (64.80 cm) and *Ceiba pendandra* (61.00 cm) (Table 3). Maximum diameter at breast height for trees in this forest is *Nauclea diderrichii* (119.95 cm), *Spathodea campanulata* (98.65 cm), *Ceiba pendandra* (96.65 cm), *Entandrophragma cylindricum* (94.30 cm), *Sterculia rhinopetala* (92.50 cm) and *Strombosia pustulata* (79.45 cm) (Table 3). Species with high relative density (RD) in the study includes *Celtis zenkeri* (12.41%), *Sterculia oblonga* (9.11%); species relative dominance (RDo) *Nauclea diderrichii* (13.35%), *Strombosia pustulata* (8.36%), *Voacanga africana* (8.36%). Results of importance value index (IVI) of tree species indicated that *Nauclea diderrichii* (7.25%)*, Celtis zenkeri* (6.30%); *Sterculia rhinopetala* (5.57%), *Sterculia oblonga* (5.48%) and *Strombosia pustulata* (4.88%) have the highest IV in this forest (Table 3).

DISCUSSION

The assessment of plant species in this study revealed that all tree inventoried were indigenous tropical hardwoods species which are of great importance to the wellbeing of the people and improves environmental sustainability. This is an indication that Okomu protected forest serves as repository of tree species and biodiversity reservoir in all ramifications. Also, tree species composition of this protected forest showcase the different levels of the conservation status of tree species, forest structure and carbon storage which provides biological functions of the forest to create conducive ecosystems interaction. In addition, the growth variable computed for this study, revealed the structure of this forest which are indication of a growing forest, with potential to sequestrate more carbon from the atmospheric carbon dioxide. The results of this study confirmed the ability of protected forests to generate high diversity of tree species, genetic material and ecological processes which are valuable in social and economic sustainability. High values of biodiversity indices were computed to determine the floristic diversity and abundance of forest cover which is important for the assessment of conservation status for this protected forest which tends to be in agreement with these studies (IIRS, 2002; Adekunle *et al.,* 2013).

The results of this study indicated that tree species of Ulmaceae (*Celtis zenkeri*), Sterculiaceae (*Sterculia tragacantha*), Fabaceae (*Baphia nitida*), Meliaceae (*Entandrophragma angolense*) and Moraceae (*Ficus exasperata*) consists of the important part of the floristic composition of Okomu protected forest. These families Meliaceae, Rubiaceae, Malvaceae, Fabaceae, Apocynaceae and Annonaceae have high importance value index than any family as observed in this protected forest. The results of this study was in agreements with several studies conducted in the tropical rainforest ecosystems of Nigeria where differences exists among the tree species composition and biodiversity indices (Adekunle *et al.,* 2013; Adekunle *et al.,* 2014; Agbelade and Adeagbo, 2020; Onyekwelu *et al.,* 2021) as indicated in Table 5. The results of the phytosocological attribute and species diversity of this study is a pointer to the effective management strategy and protection from encroachment and deforestation of the study area (Okomu protected forest). This could also be an indication of minimal ecosystem alteration and that the protected forest of Okomu is repositories of many indigenous tropical hardwood tree species of high ecological, social and economic values (Onyekwelu *et al.,* 2022). The estimated volume computed for this research is in conformity with studies conducted by Adekunle *et al.,* (2013); Adekunle *et al.,* (2014); Agbelade and Adeagbo (2020); Agbelade and Ojo (2020), as shown in Table 5. Volume estimation has been reported to be the determinant of tree growth structure and the most important parameter for the management of forest (Adekunle, 2006; Tonolli *et al.,* 2011; Adekunle *et al.,* 2013). Furthermore, methods of volume estimation could sometimes be determinants to the differences in volume estimation for various protected forests in the tropical rainforest ecosystems. The method adopted by the previous researchers for volume estimation in their studies was the analytical formula, also known as Newton's volume estimation formula (Husch *et al.,* 2003). The result of biodiversity indices are compatible with studies conducted in Akure strict nature reserve, Eda protected forest, Osun Osogbo and Igbo Olodumare sacred groves as recorded in Table 5 (Adekunle *et al.,* 2013; Adekunle *et al.,* 2014; Agbelade and Adeagbo, 2020; Agbelade and Ojo, 2020; Onyekwelu *et al.,* 2021).

Table 4. Family structure, diversity and biomass estimation

Family	FQ	BA	Vol	AGB	BGB	TCS	FRD	FRDo	FIV
Anacardiaceae	1	0.13	3.90	1.79	0.36	1.08	0.38	2.00	1.19
Annonaceae	4	0.28	14.35	6.96	1.39	4.18	6.96	4.21	5.59
Apocynaceae	4	0.99	25.17	13.29	2.66	7.98	5.19	14.75	9.97
Bignoniaceae	1	0.26	10.92	5.86	1.17	3.52	0.63	3.88	2.26
Boraginaceae	1	0.19	7.72	4.80	0.96	2.88	0.13	2.76	1.44
Caesalpiniaceae	1	0.02	1.29	1.31	0.26	0.79	0.38	0.26	0.32
Capparaceae	1	0.06	3.62	2.67	0.53	1.60	0.51	0.88	0.69
Clusiaceae	2	0.12	7.14	6.39	1.28	3.84	1.90	1.75	1.82
Combretaceae	2	0.37	20.86	12.16	2.43	7.29	2.41	5.49	3.95
Ebanaceae	3	0.10	7.56	7.56	1.51	4.53	3.54	1.53	2.54
Euphorbiaceae	2	0.12	6.41	3.66	0.73	2.19	1.77	1.78	1.78
Fabaceae	6	0.77	32.10	24.43	4.89	14.66	7.85	11.42	9.63
Irvingiaceae	1	0.03	4.42	4.21	0.84	2.53	0.76	0.44	0.60
Lecythidaceae	2	0.16	8.04	6.73	1.35	4.04	2.03	2.41	2.22
Malvaceae	6	1.19	43.36	24.02	4.80	14.41	9.75	17.76	13.75
Meliaceae	7	0.41	24.84	15.77	3.15	9.46	16.58	6.15	11.36
Moraceae	2	0.04	1.81	0.77	0.15	0.46	0.25	0.53	0.39
Myristicaceae	2	0.08	4.34	2.16	0.43	1.30	1.90	1.23	1.56
Ochnaceae	1	0.18	7.30	8.07	1.61	4.84	0.38	2.63	1.50
Olacaceae	1	0.05	3.42	3.50	0.70	2.10	10.25	0.77	5.51
Onagraceae	1	0.02	1.64	1.21	0.24	0.73	0.13	0.25	0.19
Poaceae	1	0.06	3.40	2.51	0.50	1.51	1.52	0.91	1.21
Putranjivaceae	1	0.12	4.86	4.03	0.81	2.42	0.51	1.84	1.18
Rubiaceae	6	0.42	26.64	21.78	4.36	13.07	2.66	6.23	4.44
Rutaceae	1	0.09	5.39	4.18	0.84	2.51	3.29	1.29	2.29
Santalaceae	1	0.04	2.27	1.67	0.33	1.00	0.13	0.63	0.38
Sapotaceae	1	0.01	1.70	1.28	0.26	0.77	0.13	0.15	0.14
Sterculiaceae	2	0.14	7.77	4.72	0.94	2.83	1.01	2.10	1.56
Ulmaceae	1	0.11	5.89	4.68	0.94	2.81	12.41	1.61	7.01
Urticaceae	2	0.13	8.14	3.32	0.66	1.99	2.78	1.96	2.37
Violaceae	1	0.03	2.41	2.02	0.40	1.21	1.90	0.47	1.19

Table 5. Comparison of biodiversity indices of Okomu protected forest with published results of tropical forests.

Location	Forest type	Biodiversity Indices					Volume, Biomass and carbon stock			Reference
		No. of families	No. of Species	H′	Species Richness	Species evenness	Volume (m^3)	AGB + BGB (kg)	TCS (kg)	
Okomu	NF	31	67	3.29	4.48	0.64	9437.76	6795.20	3397.60	This study
Osun-Osogbo	SG	27	50	3.19	8.05	0.84				
Igbo-Olodumare	SG	19	31	1.80	5.57	0.52				Onyekwelu *et al*., 2021
Idanre Hills	SG	26	43	3.25	7.94	0.86				
Ogun-Onire	SG	29	62	3.46	10.24	0.85				
Eda Forest Reserve	DF	17	28	2.58	5.71	0.45				Agbelade & Ojo, 2020
Akure	NF	23	56	3.49		0.86	880.58	1235.72	418.54	Agbelade & Adeagbo, 2020
Osogbo	SG	19	50	3.20		0.82	300.48	617.85	209.26	
Eda	NF						971.09	9795.65	4897.82	
Murtiya Forest	NF	20	23	2.37	4.27	0.76	702.09	10721.69	5360.84	Adekunle *et al*., 2014
Balcha Forest	NF	10	11	1.35	2.19	0.56	597.80			
Nishangara Forest	NF	12	13	1.73	2.44	0.67	617.87			Adekunle *et al.* 2013

Note: NF: Natural forest. SG: Sacred grove forest. DE: Degraded forest.

Tropical forests are known to play an important role in regulating the global carbon cycle and absorption of atmospheric carbon into the plants cell walls. The biomass of tropical forests plays critical role in micro and macro regulation of the environmental carbon cycling and carbon dioxide for forest ecosystem functions (Wittmann *et al.,* 2008). However, not all tropical forest in Nigeria land-use systems have been adequately investigated for can stock accumulation, one of which is Okomu protected forest. Ramachandran *et al.,* (2007) explained the processes involved in the absorption of atmospheric carbon dioxde into the physiological components and cell walls of the plants, during photosynthesis and the recycling of the carbon into the soil. The results of biomass and carbon stock generated in this research indicated the contributions of Okomu protected forest to carbon sequestration and climate change mitigation in Nigeria. Large diameter tress which is targeted by loggers contributed immensely to carbon sink and sequestration process than smaller tree sizes. Several researches conducted in determination of biomass and carbon storage are cited in Table 5 (Adekunle *et al.,* 2014; Chandrashekara and Sankar, 1998; Wittmann *et al.,* 2008; Agbelade and Adeagbo, 2020). The result for Akure SNR and Osun Osogbo sacred grove is lower than that of Okomu protected forest. The disparity in the values maybe as a result of the different methods and equation adopted, this study uses BEF while other researcher used allometric equations. Carbon storage of forest biomass is an important attribute of a stable forest ecosystem and a key link in global carbon cycle. The total carbon stock estimated for this study is 6795.20 kg ha^{-1} which is higher than 617.86 kg ha^{-1} recorded for Akure strict nature reserve and 209.27 kg ha^{-1} for Osun Osogbo sacred grove (Agbelade and Adeagbo, 2020). Ramachandran *et al.,* (2007) explained the processes involved in the absorption of atmospheric carbon dioxide into the physiological components and cell walls of the plants, during photosynthesis and the recycling of the carbon into the soil. The results of biomass and carbon stock generated in this research indicated the contributions of Okomu protected forest to carbon sequestration and climate change mitigation in Nigeria. Large diameter tress which is targeted by loggers contributed immensely to carbon sink and sequestration process than smaller tree sizes. The above results show that Okomu protected forest would contribute significantly to carbon sequestration and climate change mitigation as long as the forest is adequately protected from deforestation and degradation.

Based on the findings of this research, Okomu protected forest is critical habitat for biodiversity and are also essential for the provision of a wide range of ecosystem services that are important to human well-being. There are indigenous tropical tree species that have possess certain conservation status in this protected forest; near threatened (NT), endangered (EN) and vulnerable (VU) to extinction, if such species are not protected through conservation measures (FORMECU, 1999; IUCN, 2022). There is increasing evidence that biodiversity contributes to preservation of the environment, forest ecosystem functioning and the provision of ecosystem services. There is strong evidence of active forest structural dynamism, conservation of biodiversity, carbon stock and biomass accumulation in this protected forest leading to high volume of carbon sequestration potentials. This reference can be used to compare changes in carbon stocks over time. The current position of this protected forest in terms of tree species abundance, evenness, carbon sequestration, productivity and structure shows the effectiveness of *in-situ* management of the forest resources. Thus, besides being a reservoir of biodiversity, Okomu protected forest also act as sink of atmospheric CO_2. The high biomass and carbon stock in this forest reserve attributed to the effective conservation system that prevented the forest from degradation and deforestation as well as the Federal government policy on National parks.

CONCLUSION

Okomu protected forest has demonstrated high level of biodiversity conservation, volume yield and carbon sequestration capabilities through strict management procedures. Maintaining the management strategies of this protected forest would increase biodiversity conservation, structural attributes and carbon storage potential thereby performing the ecosystems functions to the environment by mitigating climate change. Also, all the species occupying this protected forest have the potential to serve as a long-term carbon sink due to its growing status and good potential for carbon sequestration. Continuous provision of ecosystem services and functions of this forest depend largely on the biodiversity conservation and strengthening of management procedure to prevent the forest from deforestation through encroachment. It is therefore recommended that strict measures should be taken to identify other protected forests such as strict nature reserves, biosphere reserves, game reserves, forest reserves, permanent plots, National parks and should be protected from anthropogenic activities.

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